OBJECTIVE EVALUATION OF COLOR OF TOMATOES FOR PROCESSING

A Report on the 1953 Studies to Develop
A Method for Use in Inspection
Procedure

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CONTENTS

The study on which this report is based was made under authority of the Agricultural Marketing Act of 1946 (RMA Title II).

SUMMARY

Difficulties have been encountered in maintaining constant color lines in the subjective evaluation of raw tomato color. The Fruit and Vegetable Division, Agricultural Marketing Service, therefore, in 1953 investigated the possibility of determining the quality of tomatoes for processing on the basis of an objective evaluation of color (using a raw juice medium) combined with a subjective determination of the percentage of grade defects.

Secondary objectives in this investigation were: (1) to test the ability of two photoelectric instruments (the Hunter Color and Color-Difference Meter and the Model "F" Agtron) to measure small differences in tomato color under field conditions, (2) to test the feasibility of having an inspector score raw tomato juice for color with the aid of a Macbeth-Munsell Disk Colorimeter, (3) to test a sampling device which was designed to remove a representative subsample for the color evaluation from the sample of tomatoes customarily used by the inspector to determine grade, (4) to determine the effect on juice color of small amounts of air incorporated during the extraction process, and (5) to test the practicability of using a standard source of illumination for grading purposes.

During the 1953 season, 470 samples of tomatoes were analyzed at processing plants located in Delaware and New York. The procedure consisted of removing, by means of a sampling device, approximately 13 percent of each three-basket sample for color evaluation. The remainder of the sample was classified by a Federal inspector on the basis of color and defects according to the specifications of the U. S. Standards. Five classifications were established on the following characteristics:

(1) Consisting of U. S. No. 1's.

(2) Consisting of U. S. No. 2's for color and U. S. No. 1's for defects.

(2d) Consisting of U. S. No. 2's for defects and U. S. No. 1's for color.

(Cc) Consisting of Culls for color and U. S. No. 1's or U. S. No. 2's for defects.

(Cd) Consisting of Culls for defects and U. S. No. 1's or U. S. No. 2's for color.

The color of the juice, extracted from the subsample, was evaluated with a Hunter Color and Color-Difference Meter, a Model "F" Agtron, and a Macbeth-Munsell Disk Colorimeter (Visual Color Score).

On the basis of this study, a series of equations was suggested for evaluating the quality of raw tomatoes based on an objective evaluation of raw juice color and a subjective determination of the percentage of grade defects. Inasmuch as the samples collected in 1953 did not represent a normal

grade range encountered in commercial operations, it is necessary that additional information be obtained on samples representing a wider range of color and defects before the coefficients for these equations can be properly evaluated.

Closely related color indices were provided by the Hunter Color and Color-Difference Meter (L, a and b) and the Model "F" Agtron (R = 0.92), on the basis of the 470 subsamples collected during the 1953 season.

On raw juice, the Hunter L, a and b values, used as a group of independent variables, provided a more accurate index than the a/b ratio used as a single variable.

Comparisons of visual color scores for raw juice (Macbeth-Munsell Disk Colorimeter) with the indices obtained with the photoelectric instruments showed a relatively high degree of relationship, as indicated by the following correlation coefficients:

Hunter a/b = 0.81, Hunter L, a and b = 0.88, and Agtron = -0.82.

There was essentially no relationship between the initial sample weights and the corresponding subsample weights separated by the sampling device. This was indicated by a correlation coefficient (r) of 0.10. The weight of the subsamples represented an average of 13.5 percent of the initial sample, with a standard deviation of 3.4 percent.

There was fairly close relationship between the grade composition of the sample (based on color) on the one hand, and the color index of the juiced subsample as measured by the Hunter Color and Color-Difference Meter, the Agtron and the Inspector (aided by a Macbeth-Munsell Disk Colorimeter) on the other hand. The multiple relationship between the Hunter a/b ratio and the proportions of tomatoes falling into classifications 1, 2c and Cc in the sample gave a correlation coefficient (R) of 0.61. Similar studies with the Agtron and Visual Juice Color Score (Macbeth-Munsell Disc Colorimeter) gave coefficients of 0.58 and 0.57, respectively.

Under the conditions of this experiment, the type of extractor used provided a satisfactory method of preparing tomatoes for color evaluation because a minimum amount of air was incorporated in the raw juice. However, the a/b ratio determined by the Hunter Color and Color-Difference Meter indicated a slightly less red colored juice after deaeration while the Agtron and Visual Score indicated slightly redder color after deaeration. Since the Hunter instrument showed different results in the previous year's study (slightly redder color after deaeration) it appears that additional study is needed on the effects of deaeration on the color of raw juice.

In so far as these studies have indicated, a grading lamp (5500-6000 degrees Kelvin) used in this study, mounted 36 inches above the grading table surface, provided a satisfactory source of illumination for grading purposes.

OBJECTIVE EVALUATION OF COLOR OF TOMATOES FOR PROCESSING

Donald E. Wilson[1] and George B. Dever, Jr.[2]

INTRODUCTION

The use of instruments for determining quality factors in certain agricultural products has stimulated the interest of tomato growers and processors in the development of an objective method of evaluating tomato color. This interest stems from the need of a more accurate color measurement or index which would serve as one of the criteria for determining the value of raw tomatoes. In addition, the potential value of an objective color index as a quality control tool has been recognized by many processors.

The basic need for an objective method for evaluating raw tomato color has been associated with difficulties encountered in making subjective interpretations of the color specifications in the Federal tomato standards. These difficulties arise in maintaining uniformity of the color concepts of different graders for the minimum color requirements of U. S. No. 1 and U. S. No. 2 tomatoes. The fluctuations in color interpretation by individual graders during the course of the harvesting season also contribute to these difficulties. For example, it is thought that graders tend to become more strict in their interpretation of color requirements for U. S. No. 1 tomatoes during a period when all tomatoes are of maximum coloration. Conversely, during a period in which the general color is poor, there is a tendency for graders to become more lenient. These variations are more closely related to inherent shortcomings in human color memory than to inability to recognize small differences in color, or to laxity or incompetence. Additional factors, such as differences in human vision, eye fatigue, and intensity and quality of illumination used for grading, influence the subjective evaluation of color.

Many of these sources of variation were recognized by Younkin in his studies (5).[3] In addition to some of the sources of variations previously mentioned, it was pointed out that failure to compensate adequately for the influence of the wall tissue-locular content ratio and the absence of adequate color references describing color limits were important factors which contributed to difficulties in subjective color evaluation. It was concluded that an objective method of color measurement is necessary if material improvement in the grading of tomatoes for color is to be attained.

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3/ Figures in parentheses refer to literature cited, pages 27 and 28.

In an effort to enable the inspector to maintain better color lines separating U. S. No. 1 from U. S. No. 2 and U. S. No. 2 from Cull tomatoes, the Fruit and Vegetable Division, AMS, in 1949, introduced hand-painted slides on plexiglas depicting the cross-section color of minimum U. S. No. 1 and minimum U. S. No. 2 tomatoes. These slides, as well as hand-painted plaster models of whole tomatoes, are used in inspector training schools and by supervisory personnel.

Further evidence of the need for an objective method of color evaluation was noted in a four-year project (1949-1952) in which the grade relationship between raw and processed tomatoes and tomato products was studied. The Fruit and Vegetable Division cooperated with the New York (6), Ohio (5), and Indiana Agricultural Experiment Stations in conducting this research. The New York and Ohio studies demonstrated that, although U. S. No. 1 tomatoes generally yielded U. S. Grade A (Fancy) canned juice or pulp, the present raw product grades for color are too broad to permit accurate prediction of the color grade of the processed product. It was also concluded that the grading procedure for raw tomatoes could be made more reliable by employing a photoelectric instrument for measuring the color of juice extracted from a representative sample of tomatoes. Similar recommendations were made as a result of a series of studies conducted by the New Jersey Agricultural Experiment Station (9, 16). The instruments used for the measurement of color in the studies mentioned were the Hunter Color and Color-Difference Meter and a modification called the Hunter Tomato Colorimeter.

Tomato grading in California is now aided by the use of a photoelectric instrument called the Agtron (Model E), which evaluates the color of the cross-section surfaces of a tomato (13). Specifications in terms of Agtron values are now used in California to define the color of minimum No. 1 and minimum No. 2 tomatoes. It has been reported that fewer disagreements concerning tomatoes of borderline color have been encountered since the introduction of this instrument.

All inspections of tomatoes for processing in California are based on the Tomato Standards, Chapter 1a, Agricultural Code of California.

As defined in both the U. S. Standards and the Agricultural Code of California, "well colored" and "fairly well colored" mean that at least 90 percent and 66 2/3 percent, respectively, of the flesh of the tomato has good red color. Even though the wording is the same, the interpretations are different. For example, when scoring tomato cross-section color in California, the color of the outer and inner walls, the placenta, seeds, and jelly all influence the color score given each fruit. Using the U. S. Standards as a basis for scoring the color of cross-sectioned tomatoes, only the outer and cross-wall color is considered.

The Model E Agtron was tested by the Fruit and Vegetable Division during the 1951 and 1952 tomato seasons in connection with tomato inspection on the basis of the U. S. Standards for Tomatoes for Manufacture of Strained Tomato Products. Since the Agtron color value is the composite of all the visible color of the cross sections, it was concluded from these studies that the instrument was not adapted for scoring tomatoes for color on the basis of the U. S. Standards for Tomatoes for Manufacture of Strained Tomato Products.

Numerous other investigators have demonstrated the application of photoelectric instruments for the evaluation of raw and processed tomato color (1, 2, 3, 4, 7, 8, 10, 11, 12, 14, 15, 17).

In view of the problems encountered in maintaining constant and accurate color lines in the subjective evaluation of tomato color, and of the recommendations of research workers and others for the adoption of objective methods, an itensified research program was undertaken by the Fruit and Vegetable Division. This research was designed to determine the possibility of utilizing one of the existing methods, or developing a new method, for use in the interpretation of color requirements in the U. S. Standards for the raw product.

In 1952, studies were conducted by the Fruit and Vegetable Division in six tomato-producing States (Maryland, New Jersey, Pennsylvania, Indiana, Ohio, and New York), where three photoelectric instruments were tested. Three different tomato media were evaluated for color: (1) the external surface color was measured with a Purdue Color-Ratio Meter, (2) the cross-section surface color was measured with an Agtron (Model E) and (3) the extracted raw juice color was measured with a Hunter Color and Color-Difference Meter and the Purdue Color Ratio Meter.[4] These analyses were conducted on tomatoes selected by several inspectors to represent the minimum color of U. S. No. 1 fruits, the maximum and minimum colors of U. S. No. 2 fruits, and the maximum color of cull fruits. Hand-painted visual aids depicting cross-section surfaces of minimum U. S. No. 1 and minimum U. S. No. 2 colored tomatoes were used by the inspectors for selecting the samples.

On the basis of approximately 400 readings, estimates of the objective color specifications defining 90 percent and 66 2/3 percent[5] "good red color"

4/ In reporting on the electronic instruments and other devices used in these studies, no guarantee is expressed or implied, nor is it to be inferred that they are recommended over other equipment not used in these experiments.

5/ Color requirements for No. 1 and No. 2 tomatoes as defined in U. S. Standards for Canning Tomatoes and U. S. Standards for Tomatoes for Manufacture of Strained Tomato Products.

were obtained. However, the ranges of color of the same classification of tomatoes as defined by the instruments were so wide due to differences in varieties and locations that it was not feasible to establish definite color indices for minimum U. S. No. 1 and minimum U. S. No. 2 colored tomatoes. Thus, it was concluded from this study that a homogeneous medium (such as the juice), measured by objective means offered the greatest possibility of obtaining accurate and reproducable evaluations of raw tomato color.

OBJECTIVES

The primary objectives of the research undertaken in 1953 were: (1) to investigate the possibility of determining the quality of tomatoes for processing, on the basis of an objective evaluation of color (using raw juice media) and a subjective determination of the percent defects, and (2) to determine the relationship between the results obtained from this method and those obtained from the method currently in use.

The secondary objectives of this investigation were: (1) to test the ability of two photoelectric instruments (the Model "F" Agtron and the Hunter Color and Color-Difference Meter) to measure small differences in tomato color under field conditions, (2) to test the feasibility of having an inspector score raw tomato juice for color with the use of visual aids, (3) to test a sampling device which was designed to remove a representative subsample for color evaluation from the sample of tomatoes customarily used by the inspector to determine grade, (4) to determine the effect on juice color of small amounts of air incorporated during the extraction process, and (5) to test the practicability of using a standard source of illumination for visual grading purposes.

METHODS

This investigation was initiated on August 3 at a processing plant at Wyoming, Del., and continued through September 1. From September 3 through October 9, the investigation was conducted at a processing plant at Albion, N. Y.

Figure No. 1 is a graphic representation of the detailed procedure, as follows:

1. The Federal inspector selected a three-basket sample from a vehicle at the unloading platform.

2. A subsample was removed from each basket by means of a Purdue sampling table 6/ and the weight removed from each was recorded. The total weight removed from the three baskets was designated as the total subsample weight.

6/ The Purdue sampling table is a table constructed to hold one basket of tomatoes, one layer deep, with nine traps, which, when released, discharge a subsample of the fruits.

Schematic representation of procedure for 1955 research

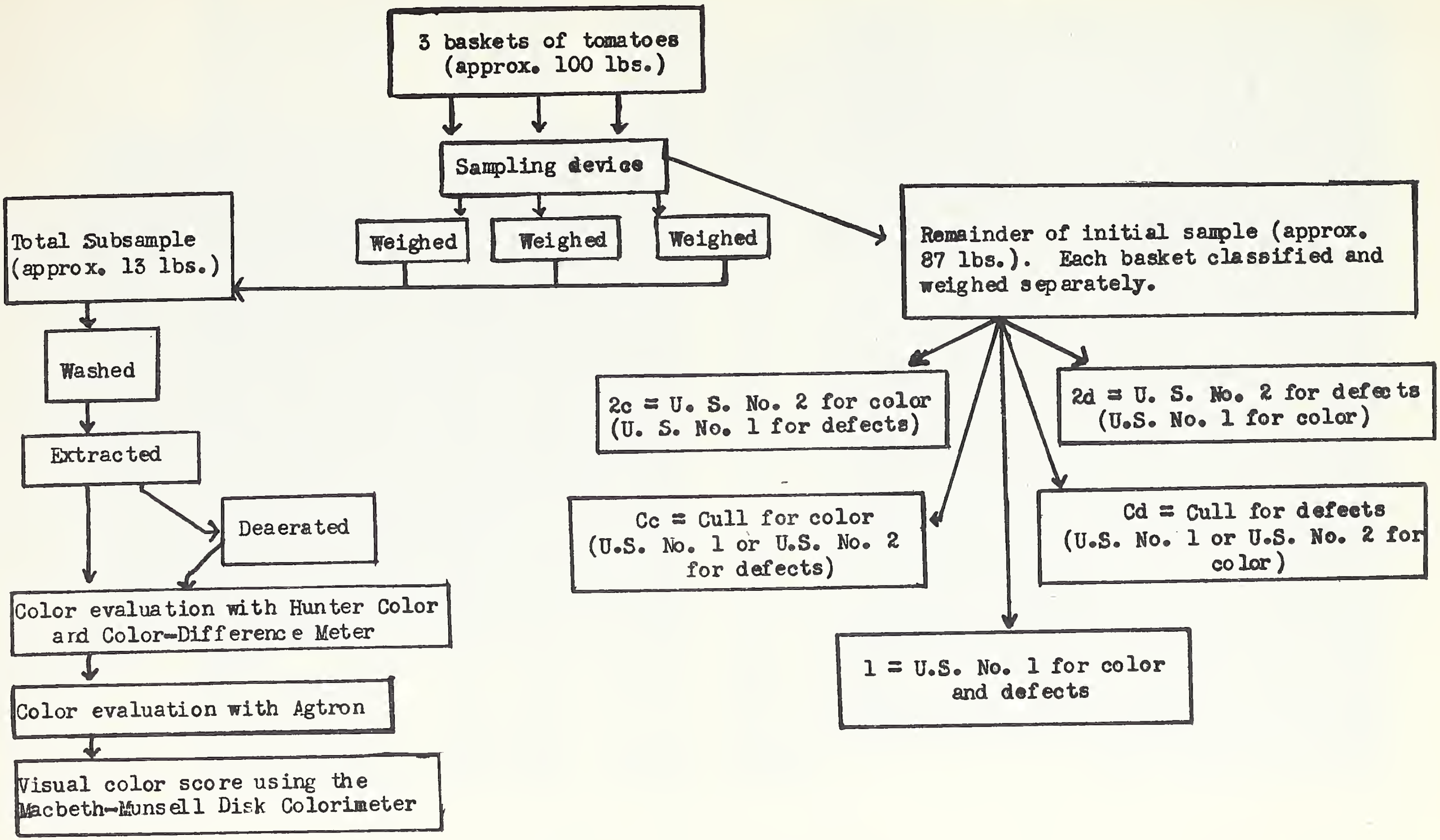

Figure No. 1

3. The remainder of each sample basket was graded by the Federal inspector on the basis of color and defects as explained in the U. S. Standards for Tomatoes for Strained Tomato Products (table 1). Hand-painted visual aids depicting the cross-section color of minimum U. S. No. 1 and minimum U. S. No. 2 tomatoes were used to facilitate grading. A metal tray (5' x 3' x 4½"), placed on a 36-inch stand, served as the grading table. A uniform source of illumination (5500 to 6000 degrees Kelvin) was supplied by a Keese Sunshine Light Unit, Model 401, mounted 36 inches above the grading table surface. Tomatoes were segregated into the following classifications:

    1. U. S. No. 1 (for color and defects).

    2c. U. S. No. 2 for color (U. S. No. 1 for defects).

    2d. U. S. No. 2 for defects (U. S. No. 1 for color).

    Cc. Cull for color (U. S. No. 1 or U. S. No. 2 for defects).

    Cd. Cull for defects (U. S. No. 1 or U. S. No. 2 for color).

   With the exception of the U. S. No. 1 classification, fruits grading the same for both color and defects were placed into the defects category of that grade. The weight of each classification (per basket) was recorded by the inspector.

4. The total subsample was washed and passed through an Enterprise food chopper (Model 2112) powered with a 60-cycle motor and fitted with a 0.027-inch mesh screen. The extractor was cleaned after each sample.

5. The extracted juice was thoroughly mixed and an aliquot of approximately 1 liter removed for subsequent color measurements. One-half of this aliquot was deaerated by placing in a five-liter vacuum flask and applying 25-30 inches of vacuum. By alternately pulling and breaking the vacuum, the air was removed in approximately 10 minutes.

6. The color of the deaerated and nondeaerated portions of the raw juice was then evaluated with a Hunter Color and Color-Difference Meter and a Model "F" Agtron. Each portion was re-mixed and a duplicate reading was obtained with both instruments. The Hunter Color and Color-Difference Meter was standardized between all samples (approximately 30-minute intervals) with a ceramic tile with L, a_L and b_L values of 27.6, 26.6, and 12.6, respectively. All readings were made with wide-aperture (2¼") and small-area 3/4"

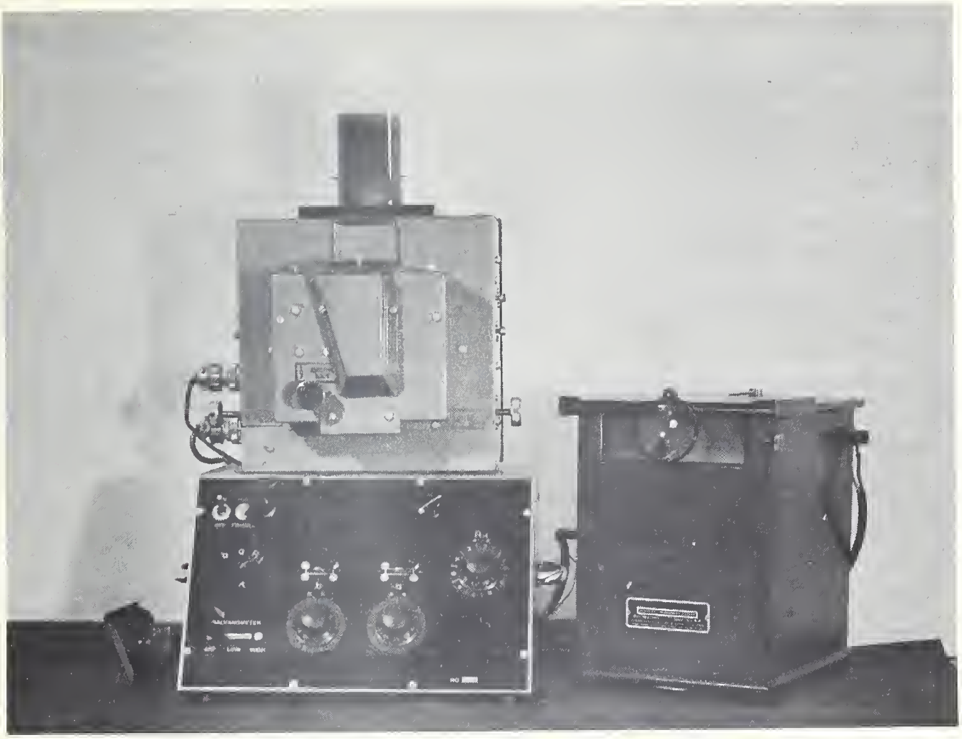

Figure No. 2. Hunter Color and Color-Difference Meter

Figure No. 3. Model "F" Agtron

Table 1. U. S. standards for tomatoes for manufacture of strained tomato[1/]

Factors	U. S. No. 1	U. S. No. 2
Color	"Well colored." 90% of flesh has good red color.	"Fairly well colored" 66 2/3% of flesh has good red color.
Firmness	Fairly firm (means not water soaked, might be soft, shriveled, or puffy; provided it is not tough or rubbery).	No requirement. Tomatoes can only be scored as culls from the standpoint of losing more than 20% in the washing process, provided they are not shriveled to the extent that they have become tough and rubbery.
Stems	Not permitted (except when the canner wishes to permit stems). Excepted cases can be handled by a statement preceding No. 1 Grade, thus: "Except for stems U. S. No. 1."	Permitted
Decay or mold	Molds or very slight decay permitted provided it can be washed out in the ordinary process of washing without hand trimming.	Permitted, provided the tomato is not sour and mold or decay can be removed in the ordinary process of trimming without a loss of more than 20% by weight of the tomato.
Sunburn, sunscald, growth cracks, catfaces, freezing injury	[2/]Free from damage.	[3/]Free from serious damage.
Worms and worm injury	Worms or worm injury that has penetrated beneath the outer wall of the tomato not permitted.	Same as U. S. No. 1
Shape	There are no shape requirements.	No requirements
Size	There are no size requirements.	No requirements

1/ Issued by the U. S. Department of Agriculture, AMS, March 1, 1933.

2/ "Damage" means any injury which appreciably affects the quality of the tomato for pulping. The quality is considered appreciably affected by the factors listed singly or in combination when the injury cannot be removed in the ordinary process of trimming without a loss of more than 10% by weight of the tomato in excess of that which would occur if the tomato were perfect.

3/ "Serious damage" means any injury which severely affects the quality of the tomato for pulping. The quality is considered severely affected by the factors listed singly or in combination, when the injury cannot be removed in the ordinary process of trimming without a loss of more than 20% by weight of the tomato in excess of that which would occur if the tomato were perfect.

Note - Cull tomatoes are tomatoes that fail to meet the requirements of either U. S. No. 1 or U. S. No. 2 tomatoes.

illumination. Throughout this study, values reported for a and b are a_L and b_L with the subscripts omitted for the sake of simplicity. The Agtron was standardized between all readings as follows: (a) with the black plastic standard placed in the viewing aperture, the meter needle was adjusted to read zero by means of the "zero" control knob, (b) substituting the red plastic standard, the meter needle was adjusted to read 60 by means of the "standardize" control knob.

7. The color of the deaerated and nondeaerated portions of the raw juice aliquot was scored by the Federal inspector using standard spinners in a Macbeth-Munsell Disk Colorimeter.7/ This instrument provides uniform illumination of approximately 7500 degrees Kelvin.

7/ The specifications and procedure for the preparation of Munsell Color Disk Standards are as follows:

(a) The Federal inspector selected approximately 10 pounds of tomatoes representing minimum U. S. No. 1 cross-section color.
(b) The tomatoes were extracted through a 0.027-inch mesh screen with the food chopper.
(c) The Munsell spinner was designed to match the color of this extracted juice and assigned the value of 20 points.
(d) By repeating steps (a), (b), and (c), with fruits representing minimum U. S. No. 2 color, a corresponding spinner was assigned the value of 10 points.
(e) The maximum-colored fruits available yielded juice with a representative spinner valued at 30 points.
(f) By blending equal portions of the juices representing 30 and 20 points, a spinner was designed to represent 25 points. Similarly, a spinner representing 15 points was constructed by matching an equal-portioned blend of 10 and 20-point juice. In this manner standards at 5-point intervals from 10 to 30 were available. Raw juice scoring lower than 10 points was not encountered.

Standard disk specifications for raw tomato juice color (1953)

Score	Munsell components in percent1/				Munsell renotation for mixture
	R	YR	N1	N4	
30	100	—	—	—	7.5R 2.92/9.9
25	93.9	2.1	1.3	2.7	7.75R 3.0/9.5
20	89.0	7.1	2.6	1.3	8.8R 3.13/9.6
15	69.3	12.0	10.7	8.0	9.25R 3.25/8.4
10	51.7	21.0	14.0	13.3	0.25YR 3.52/7.91

1/ Munsell renotations for components.

R = 7.5R 2.92/9.9; YR = 3YR 5.09/12.5; N1 = N2.5 PB 0.26/0.3; N-4 = N3.95.
The I.C.I. specifications for these notations are:
(R): X = .1102; Y = .0620; Z = .0192; (YR): X = .2856; Y = .2055; Z = .0262; (N1): X = .0030; Y = .0031; Z = .0042; (N4): X = .1132; Y = .1154; Z = .1360, respectively.

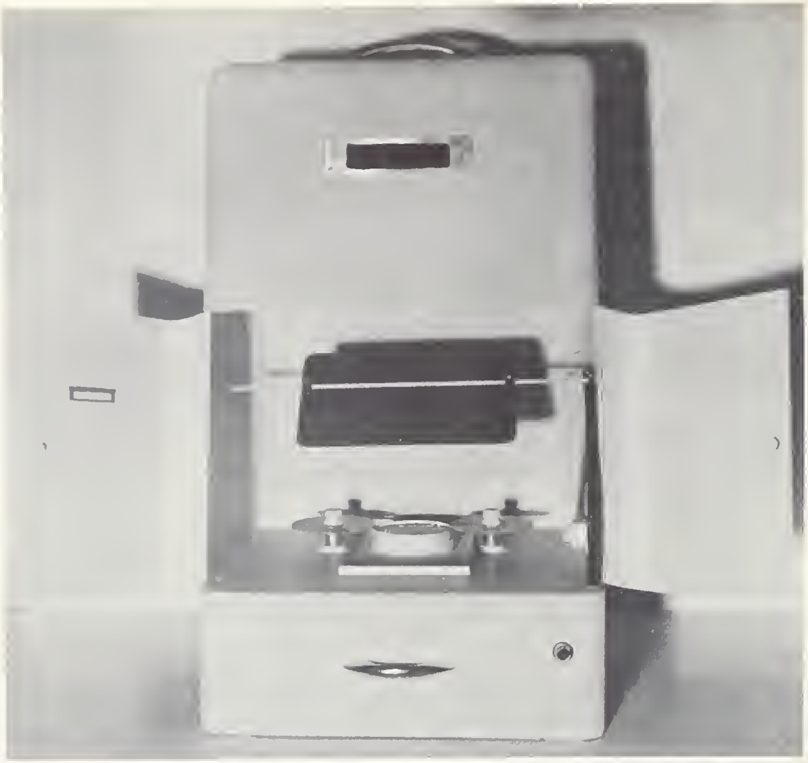

Figure No. 4. Macbeth Munsell Disk Colorimeter

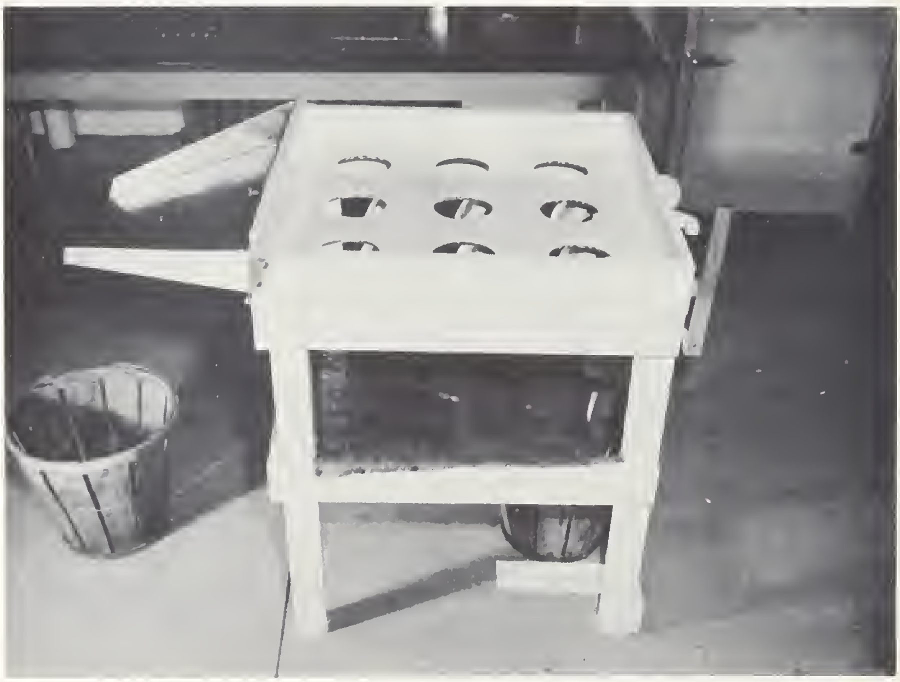

Figure No. 5. Purdue sampling table

Purdue sampling table developed by N. W. Desrosier and F. J. McArdle,
Purdue Agricultural Experiment Station

RESULTS

Color Evaluation. Duplicate color measurements of each of the 470 subsamples tested in this investigation were determined with a Hunter Color and Color-Difference Meter and a Model "F" Agtron. Visual color scores for the raw juice, using the Macbeth-Munsell Disk Colorimeter, were assigned to the last 441 subsamples. The analysis of these data was initially focused on the relationship between subjective and objective methods of color evaluation. This was deemed necessary in that the validity of the conclusions in evaluating objective methods of color measurement are dependent upon their relationship with visual color interpretations. The relationship of visual color scores to Hunter a/b ratios and to Agtron readings[8/] is shown in tables 2, 3, and 4. Table 2 lists the average Agtron and Hunter (a/b) color indices corresponding to each 2-point interval of the visual scale. The samples tested in 1953 represented a visual color range of 11 to 27 points, but approximately 69 percent were within the range of 16 to 21 points. This indicates that extremes of the color range were seldom encountered during the season. It will be noted (table 2) that a direct relationship exists between visual scores and Hunter a/b ratios, but that an inverse relationship exists between visual scores and Agtron readings.

Table 2. Relation of visual color scores of raw tomato juice to average reflectance color measurements (Hunter a/b and Agtron)

Range of visual color score	Average visual score	Hunter a/b ratio (average)	Agtron (average)	Number of samples
10-12	11.4	1.81	45	5
13-15	13.9	1.86	43	29
16-18	17.2	2.06	36	139
19-21	20.0	2.23	32	165
22-24	22.6	2.39	29	90
25-27	25.8	2.60	25	13
Total number or average	19.3	2.195	33.6	441

Table 3 shows the distribution of Hunter a/b values corresponding to each two-point interval of the visual color range. Similarly, table 4 illustrates the distribution of Agtron values with the visual scale. There was a relatively close relationship between the color scores assigned by the inspector and the indices obtained with Hunter Color and Color-Difference Meter and Agtron. Studies comparing visual scores with Hunter a/b ratios

8/ Lower Agtron readings indicate redder color.

yielded a correlation coefficient (r) of 0.81. A value of r = -0.82 was obtained when Agtron values were compared with visual scores. A higher degree of correlation was obtained when L, a and b values were used instead of the a/b ratio in comparison with visual color scores. This relationship was indicated by a multiple correlation coefficient (R) of 0.88. The regression equations for these relationships are as follows:

$$\text{Visual Score} = 14.77\ (\text{a/b ratio}) - 13.11 \qquad (1)$$

$$\text{Visual Score} = 36.06 - 0.498\ (\text{Agtron reading}) \qquad (2)$$

$$\text{Visual Score} = 32.03 - 0.26L + 1.07a - 2.92b \qquad (3)$$

These equations are based on the visual scores and instrument readings of 441 subsamples of raw tomato juice collected during the 1953 season. They are useful for estimating color scores on the basis of the instrument readings. For example, a subsample having an a/b value of 2.15 would, according to equation No. 1, have a visual rating of 14.77 (2.15) - 13.11 = 19 points.

Table 3. Relationship between Hunter a/b ratios and visual color scores of raw tomato juice collected in 1953[1/]

Visual color score	Hunter a/b ratios							
	1.4-1.5	1.6-1.7	1.8-1.9	2.0-2.1	2.2-2.3	2.4-2.5	2.6-2.7	Total Number
	Number of samples							
10-11		2		1				3
12-13	1	5	6					12
14-15		2	16	1				19
16-17			27	57	3			87
18-19			3	75	33			111
20-21				25	77	4		106
22-23					42	36	1	79
24-25					1	12	3	16
26-27						2	6	8
Total Number	1	9	52	159	156	54	10	441

1/ r = 0.81.

Table 4. Relationship between Agtron indices and visual color scores of raw tomato juice collected in 1953[1/]

Visual color score	Agtron values 20-23	24-27	28-31	32-35	36-39	40-43	44-47	48-51	Total Number
	Number of samples								
10-11				1				2	3
12-13							10	2	12
14-15				1	3	10	5		19
16-17				22	40	22	3		87
18-19			15	64	31	1			111
20-21		4	46	51	5				106
22-23	1	15	49	14					79
24-25		12	4						16
26-27	1	6	1						8
Total Number	2	37	115	153	79	33	18	4	441

1/ $r = -0.82$.

The relationship between the two objective methods for evaluating raw tomato juice color (Hunter Color and Color-Difference Meter and Agtron) is shown in table 5. For purposes of illustration, the grouped data are presented in the form of a frequency distribution. Color indices of the Hunter Color and Color-Difference Meter are computed in the form of a/b ratios. A correlation coefficient of -0.84 was obtained in a comparison of the a/b ratios and Agtron readings for the 470 samples tested. A higher degree of relationship was obtained when the Agtron values were compared with the Hunter L, a and b values by means of multiple correlation ($R = 0.92$). The regression equations for these two correlations are:

$$\text{Hunter a/b} = 3.32 - 0.33\,(\text{Agtron reading}) \qquad (4)$$

$$\text{Agtron reading} = -24.32 + 2.17L - 1.07a + 2.39b \qquad (5)$$

Table 5. Relationship between Hunter Color and Color-Difference Meter a/b ratios and Model "F" Agtron readings for 470 samples of raw tomato juice (1953)[1/]

Hunter a/b	Agtron values 20-23	24-27	28-31	32-35	36-39	40-43	44-47	48-51	Total Number
				Number of samples					
1.5-1.59								1	1
1.6-1.69							1	2	3
1.7-1.79						1	4	1	6
1.8-1.89				1	4	5	5		15
1.9-1.99				3	15	11	8		37
2.0-2.09			5	20	30	14			69
2.1-2.19			9	60	20	2			91
2.2-2.29		2	27	46	10				85
2.3-2.39	1	4	48	28	2				83
2.4-2.49		10	31	5	1				47
2.5-2.59		17	5						22
2.6-2.69		8	1						9
2.7-2.79	1	1							2
Total Number	2	42	126	168	82	33	18	4	470

1/ r = -0.84.

Several tables were prepared to illustrate the relationship between Hunter L, a and b values and visual color scores (table 6), Agtron readings (table 7), and Hunter a/b ratios (table 8). It was noted that for any constart values of "L" and "b", an increase in the Hunter "a" value was associated with an increase in the visual color score and the Hunter a/b ratio, and a decrease in the Agtron readings. (Decreased Agtron readings denote more desirable color ratings).

Table 6. Relationship between average visual score and Hunter Color-Difference Meter, L, a and b values (441 samples - 1953)

Hunter "b" values	Hunter "a" values 18.0-19.9	20.0-21.9	22.0-23.9	24.0-25.9	26.0-27.9	28.0-29.9
			Hunter "L" range = 23.0 - 24.9 Visual scores			
9-9.9		22	23	24	27	
10-10.9		21	22	23		
11-11.9				22		
			Hunter "L" range = 25.0 - 26.9 Visual scores			
9-9.9	18	20	22	24		
10-10.9	16	18	20	22	24	26
11-11.9			17	19		
			Hunter "L" range = 27.0 - 28.9 Visual scores			
9-9.9		19	19			
10-10.9	15	17	18	19		
11-11.9	14	15	16	20		
12-12.9		13	14			
			Hunter "L" range = 29.0 - 30.9 Visual scores			
9-9.9	14	16				
10-10.9	12	14	15			
11-11.9		11				

Table 7. Relationship between average Agtron reading and Hunter Color and Color-Difference Meter L, a and b values (470 samples - 1953)

Hunter "b" values	Hunter "a" values 18.0-19.9	20.0-21.9	22.0-23.9	24.0-25.9	26.0-27.9	28.0-29.9
			Hunter "L" range = 23.0 - 24.9 Visual scores			
9-9.9		30	27	26	23	
10-10.9			29	28	26	
11-11.9					28	
			Hunter "L" range = 25.0 - 26.9 Visual scores			
9-9.9	35	32	31	28		
10-10.9	39	34	32	30	28	25
11-11.9			36	35	26	
			Hunter "L" range = 27.0 - 28.9 Visual scores			
9-9.9		37	39			
10-10.9	40	39	36	34		
11-11.9	43	40	38	36		
12-12.9		47	44			
			Hunter "L" range = 29.0 - 30.9 Visual scores			
9-9.9						
10-10.9	43	47				
11-11.9	48	46	45			
12-12.9		48				

Table 8. Relationship between average Hunter a/b ratios and L, a and b values (470 samples - 1953)

Hunter "b" values	Hunter "a" values 18.0-19.9	20.0-21.9	22.0-23.9	24.0-25.9	26.0-27.9	28.0-29.9
			Hunter "L" range = 23.0 - 24.9 Visual scores			
9-9.9		2.20	2.48	2.57	2.71	
10-10.9			2.29	2.42	2.59	
11-11.9					2.42	
			Hunter "L" range = 25.0 - 26.9 Visual scores			
9-9.9	2.07	2.22	2.34	2.54		
10-10.9	1.94	2.07	2.22	2.36	2.49	2.67
11-11.9			2.04	2.22	2.39	
			Hunter "L" range = 27.0 - 28.9 Visual scores			
9-9.9		2.14	2.24			
10-10.9	1.86	1.99	2.16	2.31		
11-11.9	1.76	1.91	2.02	2.18		
12-12.9		1.82	1.91			
			Hunter "L" range = 29.0 - 30.9 Visual scores			
9-9.9						
10-10.9	1.78	1.90				
11-11.9	1.64	1.85	1.98			
12-12.9		1.65				

Conversely, for any constant values of "L" and "a" an increase in the Hunter "b" value was associated with a decrease in the visual color score and the Hunter a/b ratio and an increase in the Agtron reading. (Increased Agtron readings denote decreased color ratings). It was further noted that for constant values of "a" and "b", an increase in Hunter L value was associated with a decrease in visual color score and a/b ratio and an increase in Agtron reading. In general terms, this indicates that the color rating is directly related to the redness of the sample (Hunter "a"), and inversely related to the yellowness (Hunter "b") and lightness (Hunter "L") of the sample.

Color Range Found During the Season. Color indices, as recorded by the Hunter Color and Color-Difference Meter and Agtron, for the 470 samples collected throughout the 1953 season are shown in tables 9 and 10, respectively. For purposes of simplification, the data were grouped according to each 0.1-point gradation of the a/b scale and each 2-point interval of the Agtron scale. They were then classified according to location and date of analysis. The chronological interval was one week. The seasonal range for Hunter a/b values in Wyoming, Del., was 1.73 to 2.78 and in Albion, N. Y., 1.59 and 2.53. The seasonal average at these two locations was 2.27

and 2.14, respectively. The seasonal range for Agtron indices in Delaware was 20 to 50 and in New York, 23 to 51. The average Agtron value for all samples at these locations was 32 and 35, respectively. It was noted that the highest color indices were encountered during the first week in Delaware and the lowest color indices were encountered during the first week in New York. These tables illustrate the variation in color which existed between samples selected during the same week, as well as throughout the season, at the two locations. It was noted that, although a wide range of color was represented, the extremes of the range were not often encountered.

Table 9. Raw tomato juice color indices (Hunter a/b) representing 470 samples collected throughout the 1953 season

Color index (a/b)	Week beginning										Total Number
	8/3	8/10	8/17	8/24	8/31	9/7	9/14	9/21	9/28	10/5	
	Wyoming, Del.					Albion, N. Y.					
	Number of samples										
1.50-1.59						1					1
1.60-1.69						3					3
1.70-1.79			4			2					6
1.80-1.89			6	1	1	5	1			1	15
1.90-1.99			3	9	5	10	8			2	37
2.00-2.09	1	2	11	11	9	20	9	1		5	69
2.10-2.19		3	12	22	10	16	16	3	4	5	91
2.20-2.29	4	7	14	16	5	7	16	8	2	6	85
2.30-2.39	12	11	10	16	4	3	10	9	4	4	83
2.40-2.49	16	15	5	3			1	5		2	47
2.50-2.59	5	10	3	3			1				22
2.60-2.69	2	5	1	1							9
2.70-2.79	2										2
Total Number	42	53	69	82	34	67	62	26	10	25	470
	Average a/b values										
	2.42	2.40	2.16	2.20	2.12	2.04	2.17	2.30	2.24	2.17	2.13

Table 10. Raw tomato juice color indices (Model "F" Agtron) representing 470 samples collected throughout the 1953 season

Color index (Agtron)	8/3	8/10	8/17	8/24	8/31	9/7	9/14	9/21	9/28	10/5	Total Number
			Wyoming, Del.					Albion, N. Y.			
					Number of samples						
20-22						1					1
23-25	3	8	2	1							14
26-28	11	16	7	6	7		1	5	1	1	55
29-31	11	16	16	16	8	4	8	14	1	5	99
32-34	13	7	16	32	11	23	20	7	4	3	136
35-37	4	3	9	16	5	13	17		4	11	82
38-40		2	7	6	2	12	9			2	40
41-43		1	6	1	1	6	5			1	21
44-46			5	2		3	2			1	13
47-49				2		4				1	7
50-52			1			1					2
Total Number	42	53	69	82	34	67	62	26	10	25	470
				Average Agtron values							
	30	30	34	34	32	37	36	30	33	35	33

Relationship Between Color Grade and Color Index. The relationship between the grades assigned by the inspector on the basis of color (color grade) and the color indices of the Hunter Color and Color-Difference Meter (a/b) is illustrated in table 11. Similar illustrations comparing the relationship between the color grades and Agtron readings and between color grades and visual color scores are shown in tables 12 and 13, respectively. For this analysis the color grade represents the percentage

of classifications 1 and 2c in the subsample. This was based on the subsample weight and the corresponding color grade for the remainder of the sample.[9]

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[9] For example, the percentage of class 1 tomatoes in one total subsample (total weight removed from the three-basket sample by means of the sampling device) was determined by means of the following formula:

$$\left\{\frac{\left[\frac{\left(\text{lbs. of Class 1 tomatoes in bskt. \#1 after removal of subsample}\right)\left(\text{lbs. removed from bskt. \#1 by sampling device}\right)}{\left(\text{Sample wt. in bskt. \#1 after removal of subsample}\right)}\right]+\left[\frac{\left(\text{lbs. of Class 1 tomatoes in bskt. \#2 after removal of subsample}\right)\left(\text{lbs. removed from bskt. \#2 by sampling device}\right)}{\left(\text{Sample wt. in bskt. \#2 after removal of subsample}\right)}\right]+\left[\frac{\left(\text{lbs. of Class 1 tomatoes in bskt. \#3 after removal of subsample}\right)\left(\text{lbs. removed from bskt. \#3 by sampling device}\right)}{\left(\text{Sample wt. in bskt. \#3 after removal of subsample}\right)}\right]}{\left(\text{Total lbs. removed from bskts. \#1, 2 and 3 by means of the sampling device}\right)}\right\}100$$

The percentage of any other classification in the total subsample was calculated by substituting the weights of the desired class in the above equation. In the following example, the percentage of tomatoes classified 2c in the total subsample is determined.

Basket No.	Classifications No. 1	No. 2c	No. 2d	Cc	Cd	Sample wt. (after removal of subsample)	Subsample weight
					Pounds		
1	22	4	5	0	1	32	4
2	16	7	6	2	2	33	6
3	7	14	7	1	2	31	5
Totals	45	25	18	3	5	96	15

$$100\left\{\frac{\left[\frac{(4)(4)}{32}\right]+\left[\frac{(7)(6)}{33}\right]+\left[\frac{(14)(5)}{31}\right]}{15}\right\} = 26.87\% \text{ Class 2c.}$$

The data presented in Tables 11, 12, and 13 indicate that an increase in the percentage of U. S. No. 1 tomatoes in the subsample corresponds to an increase in color indices of the Hunter Color and Color-Difference Meter, the Agtron and visual score. Conversely, an increase in the percentage of tomatoes classified 2c corresponds to a decrease in the subjective and objective color indices.

Table 11. Relationship between average Hunter a/b ratios and the percentage of classifications 1 and 2c in 441 samples collected in 1953

Percent of classification 2c	Percent U. S. No. 1							
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79
				a/b ratio				
0-9			2.01	2.32	2.19	2.34	2.29	2.36
10-19		2.00	2.20	2.22	2.22	2.29	2.31	2.26
20-29		1.90	2.10	2.14	2.20	2.24	2.28	
30-39		1.94	2.03	2.10	2.09	2.17		
40-49		2.00	2.05	2.10	2.07			
50-59		1.95	2.06					
60-69	1.79							
70-79	1.61							

Table 12. Relationship between average Agtron values and the percentage of classifications 1 and 2c in 441 samples collected in 1953

Percent of classification 2c	Percent U. S. No. 1							
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79
				Agtron values				
0-9			31	30	31	30	30	30
10-19		36	32	32	32	32	31	32
20-29		40	36	34	34	34	33	
30-39		38	37	36	37	34		
40-49		38	36	37	34			
50-59		40	41					
60-69	44							
70-79	50							

Table 13. Relationship between average visual scores assigned to the raw juice and the percentage of classifications 1 and 2c in 441 samples collected in 1953

Percent of classification 2c	Percent U. S. No. 1							
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79
				Visual scores				
0-9			18	21	20	21	21	22
10-19		16	19	19	20	21	21	20
20-29		16	18	18	19	20	20	
30-39		16	17	18	18	20		
40-49		16	18	18	19			
50-59		16	17					
60-69	15							
70-79	12							

It was evident that perfect agreement did not exist between color grades assigned by the inspector and color indices as determined by the various instruments. The regression equations for comparing the color grade of the raw product with the corresponding color index (Hunter a/b, Agtron value or visual score) of the raw juice are shown below. The coefficients of multiple correlation (R) accompany each equation.

$$\text{Hunter a/b} = 1.878 + .006\ (\%\ \text{Class 1}) - .0019\ (\%\ \text{Class 2c}) + .0098\ (\%\ \text{Class Cc}) \quad R = 0.61 \tag{6}$$

$$\text{Agtron} = 38.997 - .111\ (\%\ \text{Class 1}) + .093\ (\%\ \text{Class 2c}) - .307\ (\%\ \text{Class Cc}) \quad R = 0.58 \tag{7}$$

$$\text{Visual score} = 13.896 + .099\ (\%\ \text{Class 1}) - .012\ (\%\ \text{Class 2c}) + .145\ (\%\ \text{Class Cc}) \quad R = 0.57 \tag{8}$$

Using equation 6 as an example, a sample having 50 percent Class 1, 25 percent Class 2c and 2 percent Class Cc should yield a raw juice having a Hunter a/b index of 2.15, i. e., $1.878 + .006\ (50) - .0019\ (25) + .0098\ (2) = 2.15$.

It will be noted that only 77 percent of the sample is accounted for. The remaining 23 percent would fall in classifications 2d or Co.

Method for Development of Modified Grading Procedure. One of the primary objectives of this investigation was to bring forward for consideration the possibility of determining the quality of raw tomatoes by means of an objective evaluation of color and a subjective determination of the percentage of grade defects. Pursuant to this objective, two instruments were tested for their relationship with one another and with the visual interpretations of raw tomato juice color. In addition, tomatoes were classified on the basis of color and defects according to the specifications of the U. S. grades (Diagram 1). By this procedure, classifications 1, 2c 2d, Cc and Cd were made available. Classifications 1 and 2d were used in conjunction with objective color indices to test the possibility of developing a modified system of grading. When classifications 1, 2c and 2d were used in combination, the grade percentages corresponding to the present system of grading were available.

Briefly, the method used to develop the formula for the modified system consisted of determining the coefficients A, B, and C and the constant D in formula No. 9.

$$\text{Price (P)} = A\left[\begin{array}{c}\text{Objective color}\\ \text{index of raw}\\ \text{juice}\end{array}\right] + B\left[\begin{array}{c}\%\ \text{Classifications}\\ 1 + 2c\ \text{in sample} =\\ \text{No. 1 for defects}\end{array}\right] + C\left[\begin{array}{c}\%\ \text{Classifications}\\ 2d + Cc\ \text{in sample} =\\ \text{No. 2 for defects}\end{array}\right] + D \tag{9}$$

This was accomplished by determining the relationship between price (P), which was calculated on the basis of the present system of grading[10] with the objective color index, the sum of classifications 1 and 2c, and the sum of classifications 2d and Cc, by means of multiple correlation. The resulting formulae or multiple regression equations, for the different methods of color evaluation, would be expressed as follows:

<u>Agtron</u>

$$\text{Price (P)} = E\begin{bmatrix}\text{Agtron}\\ \text{reading}\end{bmatrix} + F\begin{bmatrix}\text{\% classifications}\\ 1 + 2c \text{ in sample}\end{bmatrix} + G\begin{bmatrix}\text{\% classifications}\\ 2d + Cc \text{ in sample}\end{bmatrix} + H \qquad (10)$$

<u>Hunter Color and Color-Difference Meter</u>

$$\text{Price (P)} = I\begin{bmatrix}\text{Hunter}\\ \text{"L"}\\ \text{value}\end{bmatrix} + J\begin{bmatrix}\text{Hunter}\\ \text{"a"}\\ \text{value}\end{bmatrix} + K\begin{bmatrix}\text{Hunter}\\ \text{"b"}\\ \text{value}\end{bmatrix} + L\begin{bmatrix}\text{\% classifications}\\ 1 + 2c \text{ in sample}\end{bmatrix} + M\begin{bmatrix}\text{\% classifications}\\ 2d + Cc \text{ in sample}\end{bmatrix} + N \qquad (11)$$

<u>Visual Color Score (Macbeth-Munsell Disc Colorimeter</u>

$$\text{Price (P)} = P\begin{bmatrix}\text{Visual}\\ \text{color}\\ \text{score}\end{bmatrix} + Q\begin{bmatrix}\text{\% classifications}\\ 1 + 2c \text{ in sample}\end{bmatrix} + R\begin{bmatrix}\text{\% classifications}\\ 2d + Cc \text{ in sample}\end{bmatrix} + S \qquad (12)$$

Inasmuch as the samples collected in 1953 did not represent a normal grade range encountered in commercial operations, it is necessary that additional information be obtained on samples representing a wider range of color and defects before the coefficients for these equations can be properly evaluated.

<u>Sampling Device</u>. In order to determine the ability of the sampling device to separate subsamples representing a uniform percentage of the initial sample, grouped data were arranged in the form of a frequency distribution (Figure 6). This represents the subsample weights in terms of percentages of the initial sample weights. The average for 470 subsamples was 13.3 percent of the initial sample weight and the standard deviation was 3.4 percent. The coefficient of variation (relative dispersion) was 25.5 percent, indicating considerable variation in the subsample size. This does not imply, however, that a uniform percentage of

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10/ Price is currently determined on the basis of the following formula: Price (P) = T (% U.S. No. 1) + U (% U.S. No. 2). The coefficients T and U represent the dollars-per-ton value of the respective grades. The grades are based on both color and defects, as indicated in table 1, with no payment for culls.

Frequency Distribution of 470 Subsample Weights in Terms of Percentages of Initial Sample Weights. Average 13.3 ± 3.4

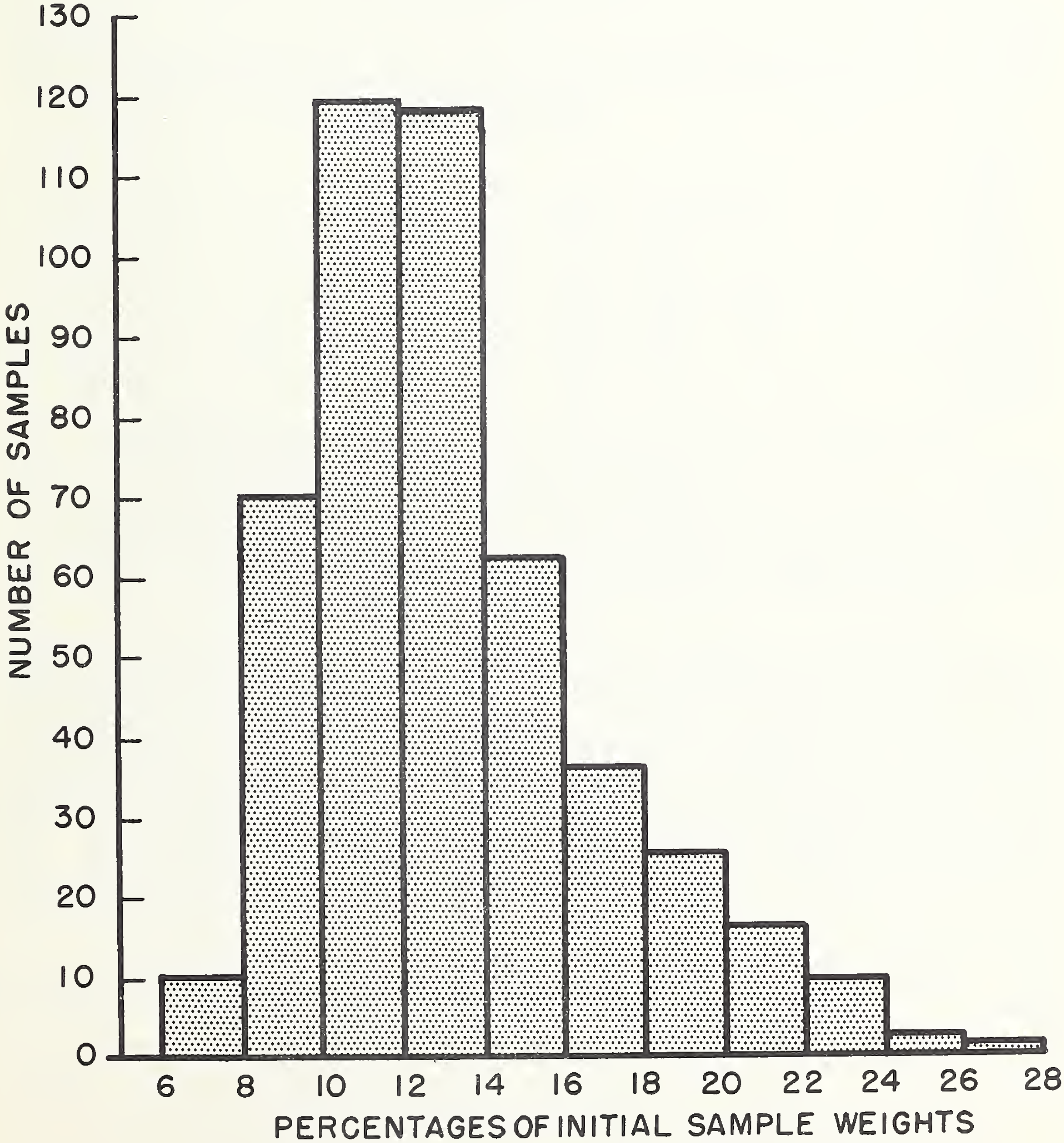

Figure No. 6

the sample would necessarily be representative. Table 14 shows the relationship between the weights of the subsamples, separated by the sampling device, and the corresponding sample weights. There was essentially no relationship between the initial sample weights and subsample weights as indicated by a correlation coefficient (r) of 0.10.[11]

Table 14. Relationship between the weights of 470 subsamples, separated by the Purdue sampling table, and the corresponding sample weights (1953)[1]

Sample weight (lbs.)	Weight of subsamples: 6.0-7.9	8.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-17.9	18.0-19.9	20.0-21.9	22.0-23.9	24.0-25.9	Total Number
	Number of Samples										
66-70		1									1
71-75			1								1
76-80			1	1	1	1	1				5
81-85			1	4	3	2	1				11
86-90		4	6	9	6	2		3	2	1	33
91-95		3	15	23	9	8	3	5		2	68
96-100	1	4	22	29	22	8	3	3	2		94
101-105	1	14	34	32	12	15	5	4	2	1	118
106-110		7	36	26	18	6	5	2	2		102
111-115		4	8	7	6	2	2	2			31
116-120				2	3					1	6
Total Number	2	37	124	133	80	42	20	19	8	5	470

1/ Subsample weight = pounds removed from 3-basket sample.

Deaeration. In order to determine the effect on juice color of small amounts of air incorporated during the extraction process, portions of the extracted subsample were evaluated for color before and after deaeration. This procedure served to test the possibility of simplifying the sample preparation technique by eliminating the deaeration process. This study was based on 157 samples collected in New York. The relationship between the color indices of the Hunter Color and Color-Difference Meter, the Agtron and the visual scores for deaerated and non-deaerated portions of the subsample is shown in tables 15, 16 and 17, respectively. Correlation studies of color indices of the deaerated and non-deaerated portions gave

11/ It was observed that the subsamples were heavily weighted with small fruits.

the following coefficients: 0.96 for Hunter a/b ratios, 0.91 for Agtron readings, and 0.91 for visual scores. These data indicate that this type of extractor provided a satisfactory tomato preparation for color evaluation because a minimum amount of air was incorporated in the raw juice. However, the average color index for the "before" and "after" readings with the various instruments were: Hunter a/b 2.16, 2.12; Agtron 35, 30; visual scores 19, 20. The Hunter indicated the color was slightly less redder color after deaeration. Since there is an unexplained difference between the reading of the Hunter and the other two indices and since these results with the Hunter instrument are different from the 1952 results, which indicated redder juice (higher a/b values) after deaeration, additional work will have to be done on the effect upon color of deaerating the raw juice.

The regression equations for the study on the effect of deaeration are as follows:

$$\text{Hunter a/b ratio after deaeration} = 0.0884 + 0.9387 \text{ Hunter a/b ratio before deaeration} \quad (15)$$

$$\text{Agtron value after deaeration} = 3.023 + 0.7626 \text{ Agtron value before deaeration} \quad (16)$$

$$\text{Visual score after deaeration} = 2.2578 + 0.941 \text{ Visual score before deaeration} \quad (17)$$

Table 15. Relationship between color indices (Hunter a/b) of raw tomato juice before and after deaeration (1953)

Hunter a/b after deaeration	Hunter a/b before deaeration 1.50-1.59	1.60-1.69	1.70-1.79	1.80-1.89	1.90-1.99	2.00-2.09	2.10-2.19	2.20-2.29	2.30-2.39	2.40-2.49	2.50-2.59	Total Number
					- - - - Number of samples - - - -							
1.50-1.59												
1.60-1.69		2										2
1.70-1.79				1								1
1.80-1.89			1	2	6	2						11
1.90-1.99				2	8	9						19
2.00-2.09					1	13	15	1	1			31
2.10-2.19						1	20	14	1			36
2.20-2.29							1	20	14			35
2.30-2.39								1	12	5		18
2.40-2.49										3	1	4
2.50-2.59												
Total Number		2	1	5	15	25	36	36	28	8	1	157

1/ r = 0.96.

Table 16. Relationship between color indices (Agtron "F") of raw tomato juice before and after deaeration[1/]

Agtron after deaeration	Agtron before deaeration 23-25	26-28	29-31	32-34	35-37	38-40	41-43	44-46	47-49	50-52	Total Number
	- - - - Number of samples - - - -										
20-22											
23-25		7	11	2							20
26-28		1	18	22	3						44
29-31			1	19	27	5					52
32-34					9	10	8				27
35-37						3	1	4			8
38-40								2	2		4
41-43									1		1
44-46											
47-49											
50-52										1	1
Total Number		8	30	43	39	18	9	6	3	1	157

1/ r = 0.91.

Table 17. Relationship between visual color scores for raw tomato juice before and after deaeration[2/]

Visual color score after deaeration	Visual color score (before deaeration) 10-11	12-13	14-15	16-17	18-19	20-21	22-23	Total Number
	- - - - Number of samples - - - -							
10-11	2							2
12-13		1						1
14-15		1	1	1				3
16-17		2	4	13	1			20
18-19				24	14			38
20-21					22	18	1	41
22-23					4	22	16	42
24-25						3	6	9
Total Number	2	4	5	38	41	43	23	156[3/]

2/ r = 0.91.

3/ The visual score for one raw subsample, by error, was not recorded.

Illumination. No test for efficiency was made on the grading lamp used in this investigation. Previous experience and observation in this study indicated that this type of light provided a satisfactory source of illumination for the grading operation. Previous studies, conducted by the Department of Agriculture, showed a high degree of correlation ($r = 0.94$) between color scores assigned to canned tomato juice when viewed under this type of grading lamp and in north daylight. It was noted that the official inspectors at each of the locations visited in this investigation were provided with this type of grading lamp.

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